Technical Note N-1424

INSPECTION OF OBJECTS RETRIEVED FROM THE DEEP OCEAN - AUTEC ACOUSTIC ARRAY

by

J. F. Jenkins

February 1976

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NAVAL FACILITIES ENGINEERING COMMAND

CIVIL ENGINEERING LABORATORY
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Information on the corrosion of materials exposed to marine environments must be obtained if ocean structures are to be designed with predictable lifetimes. A large amount of relevant information can be obtained at a relatively low cost by evaluating the condition of objects retrieved from the sea. To optimize these evaluations, they must be performed logically and uniformly. Development and application of guidelines for such evaluations can provide this optimization. As a part of the development of guidelines, this report describes an evaluation of the AUTEC acoustic array emplaced in 1962 and retrieved from the Tongue-of-the-Ocean, Bahama Islands, after 12 years of exposure. The condition of the array as well as the application and revision of the inspection guidelines are discussed.

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INTRODUCTION

In order to gather information on the performance of materials as structural components of fixed ocean facilities the Criteria and Methods Program of the Chesapeake Division (CHESDIV), NAVFAC has initiated a project to develop and apply techniques to maximize the amount, quality, and applicability of data obtained from the inspection of objects retrieved from the ocean. In order to develop techniques to maximize the benefit of these inspections, guidelines for the inspection of structures recovered from the sea have been prepared, exercised, and, as appropriate, revised. The main purpose of these guidelines is to set forth procedures for inspection of objects recovered from the sea which can be uniformly applied by field personnel with limited expertise in the field of marine corrosion and which will result in the accumulation of data which can be compared with data obtained by other field personnel from inspection of other objects. The gathering of information in this manner is cost effective when compared with normal corrosion testing because the costs of specimen procurement, specimen preparation, specimen exposure, and specimen retrieval, which are a large portion of the cost of most marine corrosion testing, are eliminated. An additional advantage of gathering information in this manner is that actual components of ocean structures are evaluated. The major disadvantage of data gathered in this manner is that, due to incomplete documentation of the structure prior to emplacement, the data are normally of a qualitative or semi-quantitative nature. Quantitative data such as corrosion rates are not normally obtainable from such inspections.

In order both to validate the guidelines for inspection of objects recovered from the sea and to gather preliminary data on the performance of materials as structural components of fixed ocean facilities, CHESDIVNAVFAC has sponsored the inspection of ''objects of opportunity'' recovered from the sea.

One such object was the AUTEC acoustic array, portions of which were retrieved from the Tongue-of-the-Ocean, Bahama Islands, in March 1974 for repair and refurbishment.

In addition to the validation of inspection guidelines and gathering of material performance data, the field inspection of the retrieved portion of the array was intended to assist in the determination of the extent to which undamaged or unrecovered portions of the existing array could be utilized in the refurbished array. Also, during a precruise standby period, a replacement acoustic string was cursorily inspected after retrieval from a 6-month test exposure in Ft. Lauderdale, Florida, Harbor.

This report is a description of the inspection and evaluation of the replacement array, the AUTEC array after retrieval, an outline of the results of the inspections and evaluations, and a discussion of the application and revision of the inspection guidelines.

ARRAY RECOVERY DESCRIPTION

As shown in Figure 1, the AUTEC acoustic array emplaced in 1962, consists of two main parts: the deep water mooring and the acoustic string. The system was so designed that the acoustic string could be retrieved and replaced without retrieving the deep water mooring. In December 1973 the upper buoy was found washed ashore. The 21-quad cable used in the acoustic string had parted at or near the cable termination on the second termination below the main buoy. It was determined during an inspection of the failed array using a manned submersible that the acoustic string had fallen on the main mooring buoy. It was then planned to retrieve the acoustic string by attaching to the bitter end of the failed 21-quad cable, raising the bitter end to the surface, and then retrieving the acoustic string in a normal manner. It was planned to replace the failed acoustic string with a new unit if the condition of the deep water mooring, as inferred from the condition of the failed acoustic string, could be expected to have a reasonable additional service life.

During 11 days of at-sea operation 1,200 feet of electromechanical (21-quad) cable, nine hydrophones, two acoustic beacons, an underwater communications transducer (UQC) and the tracking arm assembly were retrieved by the primary recovery vessel, the *R. V. Hunt*. As deck space on the *R. V. Hunt* was limited, the cable, hydrophones, beacons, and UQC were transferred to an auxiliary recovery vessel, the *J. W. Pierce*, for inspection. The tracking arm assembly was too large to safely transfer at sea, and it was inspected on the *R. V. Hunt*.

FIELD INSPECTION

The field inspection, following the guidelines included as Appendix A to this report, was made by an experienced corrosion engineer of the Navy's Civil Engineering Laboratory. A professional photographer from Lockheed Electronics Co., together with an assistant, was responsible for the retrieval and inspection photography. Technical assistance for the inspection was furnished by personnel from the Naval Underwater Systems Center, and the Naval Ship Research and Development Center. Mechanical assistance was furnished by the crew of the recovery vessels belonging to *Tracor MAS*. All inspection equipment and supplies as outlined in Appendix A, except for the crating materials, were available on site.

Visual Observations of Replacement Acoustic String

The replacement acoustic string was retrieved from Ft. Lauderdale Harbor for inspection after 6 months of exposure. The corrosion behavior of this string was of interest not only because it was to replace the failed acoustic string, but because many of the materials used in the new string were the same as those used in the failed string. Corrosion effects noted on the replacement string could therefore be used to determine which areas of the failed array should be inspected in detail.

The most severely corroded portions of the replacement string were the Monel 400 bands used to secure the rubber hydrophone boots to the hydrophone cases. Most of the bands were severely corroded due to crevice corrosion at the band-joining buckles. Many of the bands had failed completely. The 90-10 cupro-nickel hydrophone cases were very slightly etched. The electromechanical cable was unattacked. The painted steel portions of the replacement string were unattacked except for areas where the steel was exposed by abrasion. The protective coatings used were essentially intact except where mechanically damaged.

Visual Observations of Failed Array Upper Buoy

The upper buoy had been only slightly damaged by being washed ashore. Nearly all surfaces of the assembly were covered with a thick (1/8-inch to 1/4-inch) accumulation of encrusting coral. Fresh mechanical damage to the structure could be easily identified by the lack of encrusting coral on the surface at the point of damage. The steel tube support structure was corroded slightly at a few areas of paint failure, particularly on the top sides of the structural members. This could have been due to personnel climbing on the structure prior to deployment. The four steel buoyancy spheres had a few areas of minor pitting up to 1/8-inch deep. The paint coating, where visible due to the flaking off of the encrusting coral, was reasonably intact and relatively free from blistering, flaking, or chalking.

The electromechanical cable termination* at the base of the buoy had been previously disassembled and details of its condition upon retrieval were not well documented. However, as for many of the other terminations retrieved and inspected, the minimum diameter of each armor wire was measured upon disassembly and was recorded. This information was used by NSRDC in evaluating the condition of the terminations in an attempt to infer the condition of the terminations which were not recovered.

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* In this report all points where the armor wires are discontinuous are referred to as terminations, even when the termination is used only as an electrical conductor breakout.

Electromechanical (21-Quad) Cable

The cable had parted at the upper end of the second breakout housing below the upper buoy. The failed end of the cable showed significant corrosion of most of the outer and inner armor wires. The attack was localized at the areas of the wire where the polyethylene jacketing on the individual wires had been removed in assembling the terminations. The galvanized coating on the wires was intact under the polyethylene jacketing but was not present on most of the wires adjacent to the point of failure.

The only significant corrosion of the entire 1,200-foot-long section of electromechanical cable retrieved was at the cable terminations. This attack was localized adjacent to and just inside the outer edge of the wire-retaining slots in the termination. At these areas the protective polyethylene jacket had been removed from the wires in order to assemble the termination. The corrosion preventive compound used to fill the interior of the termination housings was, in most cases, not present in this critical area. There was a general trend for the presence of more of this corrosion preventive compound in those housings exposed at a greater depth on the array. In order to quantitatively evaluate the condition of the electromechanical cable at the terminations thirteen terminations were disassembled for inspection. The minimum diameter of each wire was measured. The data from these measurements was analyzed by NUSC in an attempt to predict the remaining life of the unrecovered cable at the terminations. The only trend noted in a field evaluation of this data was that the wires, particularly the inner armor wires, were less corroded in those terminations which had retained a large amount of corrosion preventive compound than in those terminations which had retained little corrosion preventive compound. As noted above, retention of this compound was generally, but not reliably, a function of depth. It was noted during these inspections that approximately 50% of the wires were not properly seated in the termination block. Eleven terminations and a 25-foot section of cable were retained by NUSC and NSRDC for further analysis.

Cable Termination Housings

The steel termination housings were in good to fair condition. The most severe attack was on the end sleeves. However, penetration of these end sleeves (1/8-inch original thickness) was noted in only two cases. A thin, patchy deposit of copper was noted on the surfaces of many of the housings. This was most probably due to substitution of electrogalvanizing for hot-dip galvanizing on the housings. Electrogalvanizing generally employs a thin copper plating, or flash, over the steel to promote good adhesion of the electrodeposited zinc coating. This copper deposit can, and probably did, lead to galvanic attack of the portions of the housing which did not originally have, or did not retain, the copper deposit. As no copper deposits were found on the end

sleeves the fact that these portions of the housings were more severely attacked than the housing bodies can be explained by this effect.

Hydrophone Cases

The hydrophone cases were fabricated from either 90-10 cupro-nickel or 70-30 cupro-nickel. The 90-10 cupro-nickel housings were uniformly etched and had a thin blue-green patina on much of their surfaces. The weld beads and heat-affected zones were in the same condition as the remainder of the housings. No difference in attack was noted in the housings exposed at different depths.

The hydrophone cases fabricated from 70-30 cupro-nickel were also uniformly corroded except for some shallow linear attack in the heavily deformed hydrophone support tubes. No accelerated weldment attack was noted.

All the monel bands used to secure the protective rubber boots to the hydrophone supports showed some signs of crevice corrosion, particularly at the band joining buckles. Two bands were found to have completely failed.

The insulating blocks used to electrically isolate the hydrophone cases and other copper-alloy instrument cases from their respective steel termination housings had retained their original effectiveness. Resistance between the cases and the housings was in excess of 1,000 ohms.

Tracking Arm Assembly

The tracking arm assembly consisted of a steel center section with aluminum outer sections. The steel center section was covered with a very thin layer of tan corrosion products as is typical of the corrosion products on galvanized steel after depletion of the zinc coating. No copper deposits were noted on the steel structure. No significant corrosion of the steel structure was evident. At the ends of the open tubular sections of the central portion of the tracking arm assembly there were stalactite like rust tubercules. These tubercules were up to 8 inches long and 2 inches in diameter. Their hard outer skins (1/4-inch thick) covered softer and often fluid interiors. After several hours exposure to the air the tubercules became brittle and crumbled. The interior portions of the tubular steel members which showed these tubercules were uniformly corroded.

The aluminum sections of the tracking arm assembly were heavily corroded. This corrosion was most severe on the portions of these sections nearest the steel center section. As the aluminum and steel were separated by nonmetallic isolation blocks which had retained an insulation resistance of over 1,000 ohms between the steel and aluminum sections, galvanic corrosion between the dissimilar metal sections was not the cause of this localization of attack. There were, however, red deposits on the central portions of the aluminum tracking arms. The

electromechanical cable just above the tracking arm assembly was heavily coated with copper-based antifouling compound. The red deposits were assumed to be copper (which was later verified) which would explain the localization of the attack of the aluminum structure most directly beneath the source of copper. The aluminum structure in electrical contact with the 70-30 cupro-nickel hydrophone cases at the ends of the tracking arms was severely corroded by galvanic action.

Array Counterweight Cable

Approximately 10 feet of the 3.75-inch wire rope array counterweight cable was available for inspection. The outer wires were 100% rusted. However, corrosion of these wires was not severe. No broken wires were located. The inner strands of the cable had retained much of their original lubricant coating. The inner strands of the cable were essentially uncorroded.

LABORATORY EVALUATION

Samples of joints from both the steel and aluminum portions of the tracking arm assembly were returned to CEL for analysis. Also, several samples of corrosion products from various portions of the array and several small hardware items were retained by CEL for analysis.

Evaluation of Tracking Arm Joints

The aluminum tracking arm joint was analyzed chemically and found to be aluminum alloy 6061. Chemical analysis of the weld metal was typical of deposits obtained with 5356 welding wire. The maximum pit depth measured on this section was 0.200 inch. The pits were randomly distributed with a frequency of $\approx$1 pit per square inch. Microstructural analysis showed these pits to be intergranular in nature. The weld beads were less corroded than the adjacent parent metal. There was no accelerated attack at the heat-affected zones adjacent to the welds. It was noted, however, that corrosion was accelerated at areas which had been covered with electrical tape during exposure. Mechanical tests of the section resulted in failures of the tubular sections; the weld joints did not fail. The ultimate strength of the tube sections averaged 56% of the rated breaking strength of unexposed 6061-T6 tube. However, the elongation was reduced from a rated 12% to an average of 4%. This reduction of elongation is typical of aluminum alloys which are subject to pitting.

The steel section of the structure was analyzed chemically and found to be typical of A-36 structural steel. The section was corroded uniformly. Tensile tests of coupons from the tubes showed no loss of material properties compared with typical properties of A-36 steel.

Analysis of Corrosion Products

Analysis of corrosion products removed from various array components identified their major constituents to be as follows.

1. from 70-30 Cupro-nickel hydrophone cases: $Ni(OH)_2$, $CuCl_2$
2. from 90-10 Cupro-nickel hydrophone cases: $Ni(OH)_2$, $CuCl_2$, CuO
3. red material from aluminum tracking arm section: Metallic Cu, Cu_2O, amorphous $Al_2O_3 \cdot XH_2O$, NaCl, Metallic Al
4. Corrosion products from monel bands: $CuCl_2$, CuO, $Ni(OH)_2$

RESULTS OF INSPECTION, SAMPLE EVALUATION, AND RECOMMENDATIONS

Considering the duration of exposure, the array was in remarkably good condition. Except for the corrosion of the armor wires of the electromechanical cable at the terminations, the galvanic corrosion between the aluminum tracking arm sections and the hydrophone cases, the corrosion of the aluminum tracking arm sections due to copper ion contamination, and the crevice corrosion of the monel bands on the hydrophone boots there was little significant corrosion of the array. The aforementioned corrosion problems can be avoided by changes in future designs.

The electromechanical cable terminations can be augmented with flexible boots to retain the corrosion preventive compound in the critical area where the protective jacketing is removed from the wires. The galvanic corrosion between the hydrophone cases and the aluminum tracking arm section can be eliminated by electrical isolation such as that used in the steel/aluminum joint on the tracking arm assembly. The copper ion contamination-caused corrosion of the aluminum tracking arm sections can be avoided by eliminating heavy metal (copper, mercury) antifoulants from the vicinity of bare aluminum structures. The antifoulants are not generally needed in the deep ocean to prevent the heavy accumulation of fouling organisms normally encountered in shallow ocean environments. The crevice corrosion of the monel bands can be reliably eliminated either by selection of an alternate material resistant to crevice corrosion or by cathodic protection of the monel bands.

EVALUATION OF GUIDELINES FOR INSPECTION OF OBJECTS RECOVERED FROM THE SEA

The interim guidelines for inspection of objects recovered from the sea (Appendix A) were found to be technically applicable to the evaluation of the AUTEC array. The guidelines were useful in explaining to the recovery team what was planned for the inspection and for giving personnel assisting in the inspection an overview of the procedures to be used.

However, it was determined that the guidelines presented in Appendix A did not cover an essential, in fact crucial, part of the inspection — prerecovery planning.

The interim guidelines were, therefore, revised to include a section on prerecovery planning. These revised guidelines are included as Appendix B of this report and should, until superseded, be used as new interim guidelines for the future inspection of structures recovered from the sea.

CONCLUSIONS

By a systematic evaluation of objects recovered from the sea, data obtained can be used for predicting the additional useful life of the object, modifying the existing object to extend its life, or designing new ocean structures. The usefulness of these data can be maximized by application of standardized guidelines for inspection of such objects. The interim guidelines presented in Appendix A were found to be technically applicable but deficient in coverage of prerecovery planning. Appendix A is included in the report to document the procedures used to obtain the information on the condition of the AUTEC acoustic array. Appendix B is an improved version of these guidelines and should be used for subsequent inspections.

The recovered sections of the AUTEC acoustic array were in remarkably good condition. The most structurally significant deterioration was that of the armor wires of the electromechanical cable at the cable terminations.

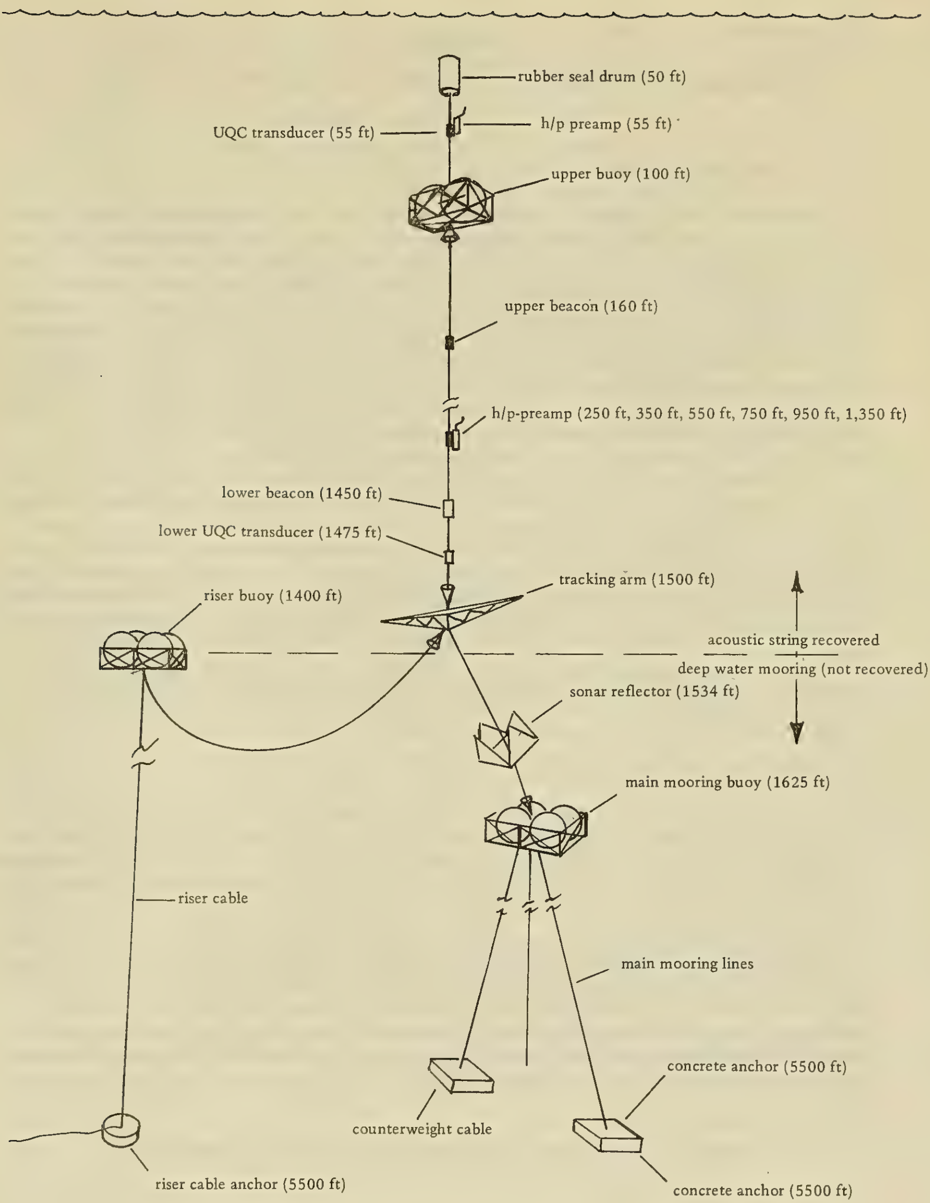

Figure 1. AUTEC acoustic array.

Appendix A

GUIDELINES* FOR INSPECTION OF STRUCTURES RECOVERED FROM THE SEA

(Revised October 1973)

I. Initial Inspection

The structure should be inspected as soon as possible after recovery. This is important because of the effect of air on the appearance of the structure, especially the corrosion products and biological growth. The items of major interest during this phase of the inspection are the amount, appearance, and distribution of biological growth and corrosion products, the condition of protective coatings, and the overall external condition of the structure. Samples of biological growth and corrosion products should be taken at this stage of the inspection and preserved as indicated in section IV below. As the pace of the inspection at this stage should be fairly rapid it is preferable that the sampling be performed by assistants at the direction of the inspector.

Documentation at this stage of the inspection is both difficult and vitally important. Visual observations should be recorded in writing or on tape. Careful attention must be given to the location of the areas inspected in order to properly interpret the observations. Photographs should be taken at this stage by the inspector or at his direction. Overall and closeup color photographs should be taken and, if practical, also black and white photographs. The locations of the areas photographed, especially the closeups, should be carefully identified and recorded.

After the initial inspection, sampling, and photographing of the structure are complete, the structure should be carefully rinsed with fresh water.

II. Detailed Inspection

This stage of the inspection can be performed at a more deliberate pace than the initial stage, as the appearance of corrosion products and biological growth is not as important at this stage. The primary objective of this inspection is the discovery of hidden damage, the identification of the type of the attack, and an assessment of the extent of damage to the structure by corrosion or other causes. Hidden attack is most often discovered by disassembly of the structure. Crevice corrosion can often be located by bleeding of corrosion products from crevice areas. The type of attack can often be identified by inspection (uniform attack, pitting, crevice corrosion, etc). However, some forms of attack must be verified by laboratory analysis (intergranular attack, stress corrosion cracking, hydrogen embrittlement, etc). The assessment of the extent of

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* These guidelines have been superseded by those in Appendix B.

damage should be made by both subjective observation and by quantitative measurement of section thickness, depth of pitting, etc. Damage due to causes other than corrosion such as impact, overload, etc., should be identified.

Samples of the structural components should be taken at this time for further laboratory analysis to verify the type and extent of damage. Samples should be removed and preserved as indicated in section IV below. This removal and preparation can be done by the inspector in many cases; however, as it may involve the use of power tools or flame cutting equipment, assistance from other personnel is often required.

Documentation of this stage of the inspection is important but the slower pace makes this duty easier to perform than initial inspection. Visual observations should be recorded in writing or on tape. Careful attention must be given to the location of the areas inspected in order to properly interpret the observations. Photographic documentation should be performed at this stage to record the extent of damage to the structure. Again, indexing of the photographs is important.

After this stage of the inspection the structure should be retained, if practical, for possible future analysis.

III. Laboratory Analysis

The techniques used for the analysis of corrosion product, biological, and material samples will, of course, depend on the material to be analyzed and the desired results. Written or photographic documentation of observations and results of testing performed are an important part of the laboratory analysis.

A. Corrosion Products. X-ray fluoresecnce spectography, emission spectography, or wet chemical analysis can be used to identify the elemental constituents of the corrosion products. X-ray diffraction can be used to identify crystalline chemical compounds in the corrosion products. Microscopic techniques can be used to determine the morphology of the corrosion products.

B. Biological Samples. The genus and species of the samples should be identified by a marine biologist. Often, in the deep ocean, new species are discovered or known species are found outside their normally defined habitat.

C. Metallic Samples. Specimens should be subjected to mechanical tests, hardness tests, metallographic examination, and other tests as necessary to evaluate the extent and type of damage to the test samples.

D. Other Materials. Samples of other materials should be analyzed in the laboratory with guidance or assistance from personnel with expertise in their field.

IV. Sampling and Sample Preservation

The most important factor in sampling and sample preservation is to retain, in a useable form, all of the information available from the sample until the information can be extracted. The original location, orientation, and appearance of the sample should be documented. The sample should be removed carefully, properly preserved, and transported to the analyzing facility.

A. Biological Samples. Most biological samples can be removed from the structure by careful scraping or other means or they can be removed with the substrate. The samples should then be placed in labeled bottles or jars and covered with ethyl alcohol containing 5% glycerine or with a 5% solution of formalin in water. The containers should be well sealed.

B. Corrosion Products. Corrosion products can be removed from the structure by careful scraping, or they can be removed with the substrate. The optimum preservation method is to place the products in labeled bottles or jars and covered with fresh seawater. A second method is to place the moistened products in marked plastic bags, subsequently sealed.

C. Metallic Specimens. Small components should be removed intact; samples from larger components should be removed by sawing, chiseling, or other method. Flame cutting is undesirable but is often necessary. When flame cutting is used, the sample area should be cooled with wet rags or other means, and left with a 2- to 3-inch margin around the area of interest because the heat of the flame can seriously affect the condition of many samples. Small metal samples can be preserved by placing them in labeled bottles or jars and covering them with n-butanol. Larger samples should be rinsed with fresh water, dried, and sealed in marked plastic bags.

D. Other Materials. Other materials should be removed so as to minimize damage and preserved according to guidance given by personnel with expertise in their handling.

E. Transport of Samples. The samples should be packaged in sturdy wooden crates and transported by air freight or rapid surface transport to the analyzing facility.

V. Personnel Requirements for On-site Inspection

A. Basic Requirements

1. Inspector - a corrosion engineer experienced in evaluating structures after deep-ocean exposure.

B. Desirable Additional Requirements

1. Photographer - person familiar with closeup photographic techniques; preferably a qualified, professional, Navy photographer.

2. Technical Assistant - person familiar with the inspection, sampling, and sample-preservation techniques to be utilized.

3. Mechanical Assistant - person assigned to the inspector for removing material samples and for other duties,

VI. Equipment and Supply Requirements

A. Basic Requirements

1. Photographic Equipment and Supplies

   a. 35-mm SLR camera with through-the-lens metering and closeup capability.

   b. Lenses

      (1) Wide angle, approximately 30-mm.

      (2) Normal, macro, approximately 50-mm with focal distance of ∞ to approximately 12 inches.

      (3) Telephoto, macro, approximately 90-mm, with focal distance of ∞ to approximately 12 inches.

   c. Electronic flash (strobe) for camera.

   d. Normal or high-speed Ektachrome film. Requirements normally vary from 50 to 250 exposures.

2. Inspection and Miscellaneous Equipment and Supplies

   a. Tools for component disassembly. Usually will be available on site from ship's engineer. Check availability.

   b. Picks, probes, sampling equipment, etc. Should be brought by inspector.

   c. Sample preservation equipment, inspector-supplied. Bottles, jars, plastic bags, etc., and preservative solutions as outlined in Section IV above.

   d. Fresh water for rinsing. Usually supplied by ship via a hose, although a pneumatic sprayer can be used. The ship should be notified of this requirement.

   e. Cutting tools for large samples. Usually available on site from ship's engineer. Check availability.

   f. Notebooks and pens or pencils for recording of data.

   g. Boxes and packing material for transporting samples. Usually available or can be fabricated on site. Check with ship's personnel or with cruise leader prior to departure.

B. Desired Additional Requirements

1. Photographic Equipment and Supplies

   a. Large format (2-1/4 x 2-1/4, 120, or 4 x 5) camera for black and white photographs.

   b. Wide angle, normal (macro) and telephoto (macro) lenses for above. Close-up capability is desired.

   c. Flash equipment or flood lamps for camera.

   d. Film for camera. Plus-X Panchromatic film preferred. Amount of film required will vary from 50 to 250 exposures.

2. Inspection and Miscellaneous Equipment and Supplies

   a. Flame cutting equipment and operators. This will usually be available on site. Check availability.

VII. Reporting of Results

The final report should be either an informal report, technical note, or technical report. The informal report can be prepared most rapidly for limited distribution; the technical note or report requires more time for preparation but is published in a more polished form and has a wider distribution. The preparation of a short informal report followed by a detailed technical note or report should be considered. A target date for completion of the draft report should be 90 days from the completion of the recovery.

The report should contain a detailed description of the damage incurred by the structure and a report of the results of the laboratory analysis. Photographs should be included in the report. The conclusions should include an assessment of the damage, its probable cause, the expected lifetime of similar structures, and methods of extending the lifetimes of similar structures. Unexpected corrosion damage should be identified, and recommendations for further studies should be made.

Appendix B

GUIDELINES FOR INSPECTION OF STRUCTURES RECOVERED FROM THE SEA

(Revised April 1975)

I. Prerecovery Planning

The recovery of structures from the sea and the inspection of the structures for documentation of their response to the marine environment usually involves the cooperative effort of several groups. For maximum information from inspection of the object each group must be aware of the procedures to be followed in the retrieval and inspection of the object. The inspection plan should be incorporated into the overall cruise plan; however, the inspection plan can be integrated into the cruise plan as an appendix or addition.

The inspection plan must be mutually agreeable to all participants in the recovery including the sponsor of the inspection, the inspection team, the sponsor for the recovery, all groups participating in the recovery, and the owner or group responsible for the structure. The following outline is intended to be a general guideline for the preparation of a precruise plan. Portions of the plan outlined below may not be applicable to every inspection, and in some cases additional information will be required.

The outline for the inspection plan should be discussed with the groups participating in the recovery and inspection. An ideal forum for such a discussion is a precruise meeting, which is often held in conjunction with the preparation of a cruise plan. Integration of the inspection plan into the overall cruise plan at this stage usually will result in an optimum inspection. As an absolute minimum an inspection plan should be formulated prior to the recovery and approved by the group responsible for the recovery prior to the recovery.

OUTLINE FOR INSPECTION PLAN

A. Background

1. Structure to be inspected

   a. Name

   b. Size and shape (drawings or photos, if available)

   c. Location (geographical and depth)

   d. Portions to be retrieved

   e. Security classification

2. Participants

    a. Inspection sponsor

    b. Inspection team

    c. Recovery sponsor

    d. Recovery participants

    e. Structure owner

3. Planned recovery timetable (may not initially include inspection)

B. Purpose of Inspection

1. Specifications usually by inspection sponsors (all participants must agree).

2. Purposes (usually one or more)

    a. Evaluation or improvement of inspection techniques

    b. Information for future designs of general nature

    c. Information for revision of specific similar designs

    d. Documentation of condition of structure for refurbishment or replacement of the structure or similar structure if many in service

    e. Identification of deficiencies in ability to predict the response of structures to marine environments.

C. Requirements for Inspection

1. General requirements (see sections II, III, and V of these guidelines)

    a. Determination of availability and accessibility of the structure for inspection, including safety considerations

    b. Determination of number and location of samples to be taken and indications of which portions of the object may not be disturbed or removed

2. Specific equipment or material (see sections VI and VII of these guidelines) and identification of specific person or group responsible for each item.

    a. Specific problem areas often encountered in inspections that should be discussed and possibly documented prior to inspection

        (1) Time of arrival and departure of inspection team

        (2) Inspection team personnel

(3) Security clearances required

(4) Passports and visas required

(5) Quarters and meals for inspection team during operations

(6) Transportation for inspection team

(7) Support needed by inspection team (photographers, riggers, welders, etc.)

(8) Materials needed by inspection team to be furnished by others (boxes for samples, cable cutters, welding equipment, lights, tools, etc.)

(9) Personnel to be allowed in vicinity of structure before, during, and after recovery (necessary to reduce damage by ''souvenir hunters''

(10) Specific information on special equipment needed by the inspection team (foul-weather gear, personal effects, etc.)

(11) Availability of inspection team personnel for auxiliary duties during recovery

3. Funding for inspection and documentation (determine in advance each sponsor's contribution as well as each sponsor's need for inspection or documentation).

D. Requirements for postrecovery operations

1. Determination of disposition of samples, including crating and shipping of test samples

2. Forwarding to the inspection team pertinent data obtained by various groups during the recovery, the extent of documentation required – recovery times, observations, photographs, oceanographic data – and the timetable for submission

3. Content and distribution of reports on the inspection

4. Funding of this portion of the inspection

II. Initial Inspection

The structure should be inspected as soon as possible after recovery. This is important because of the effect of air on the appearance of the structure, especially the corrosion products and biological growth. The items of major interest during this phase of the inspection are the amount, appearance, and distribution of biological growth and corrosion products, the condition of protective coatings, and the overall external condition of the structure. Samples of biological growth and corrosion products should be taken at this stage of the inspection and preserved

as indicated in section IV below. As the pace of the inspection at this stage should be fairly rapid it is preferable that the sampling be performed by assistants at the direction of the inspector.

Documentation at this stage of the inspection is both difficult and vitally important. Visual observations should be recorded in writing or on tape. Careful attention must be given to the location of the areas inspected in order to properly interpret the observations. Photographs should be taken at this stage by the inspector or at his direction. Overall and closeup color photographs should be taken and, if practical, also black and white photographs. The locations of the areas photographed, especially the closeups, should be carefully identified and recorded.

After the initial inspection, sampling, and photographing of the structure are complete, the structure should be carefully rinsed with fresh water.

III. Detailed Inspection

This stage of the inspection can be performed at a more deliberate pace than the initial stage, as the appearance of corrosion products and biological growth is not as important at this stage. The primary objective of this inspection is the discovery of hidden damage, the identification of the type of the attack, and an assessment of the extent of damage to the structure by corrosion or other causes. Hidden attack is most often discovered by disassembly of the structure. Crevice corrosion can often be located by bleeding of corrosion products from crevice areas. The type of attack can often be identified by inspection (uniform attack, pitting, crevice corrosion, etc). However, some forms of attack must be verified by laboratory analysis (intergranular attack, stress corrosion cracking, hydrogen embrittlement, etc). The assessment of the extent of damage should be made by both subjective observation and by quantitative measurement of section thickness, depth of pitting, etc. Damage due to causes other than corrosion such as impact, overload, etc., should be identified.

Samples of the structural components should be taken at this time for further laboratory analysis to verify the type and extent of damage. Samples should be removed and preserved as indicated in section IV below. This removal and preparation can be done by the inspector in many cases, however, as it may involve the use of power tools or flame cutting equipment, assistance from other personnel is often required.

Documentation of this stage of the inspection is important but the slower pace makes this duty easier to perform than initial inspection. Visual observations should be recorded in writing or on tape. Careful attention must be given to the location of the areas inspected in order to properly interpret the observations. Photographic documentation should be performed at this stage to record the extent of damage to the structure. Again, indexing of the photographs is important.

After this stage of the inspection the structure should be retained, if practical, for possible future analysis.

IV. Sampling and Sample Preservation

The most important factor in sampling and sample preservation is to retain, in a useable form, all of the information available from the sample until the information can be extracted. The original location, orientation, and appearance of the sample should be documented. The sample should be removed carefully, properly preserved, and transported to the analyzing facility.

A. Biological Samples. Most biological samples can be removed from the structure by careful scraping or other means, or they can be removed with the substrate. The samples should then be placed in labeled bottles or jars and covered with ethyl alcohol containing 5% glycerine or in a 5% solution of formalin in water. The containers should be well sealed.

B. Corrosion Products. Samples of corrosion products should be retained for analysis. Sampling should be performed according to Section 3 of the NACE Standard RP-01-73. This standard recommends removal of corrosion products in place on the substrate, if possible. If this is not possible, removal of the corrosion product from the substrate using a nonmetallic or porcelain spatula, or hardened steel pick is recommended. The corrosion product should include any moisture present. The pH of the corrosion product should be determined by placing a short strip of pH-indicator paper on the damp corrosion products (moisten with seawater if necessary) and comparing the resultant color of the pH paper with the reference standard furnished with the pH papers. The corrosion products should be collected in individual, labeled, wide-mouth, plastic jars or in plastic bags and sealed to prevent loss of moisture.

C. Metallic Specimens. Small components should be removed intact; samples from larger components should be removed by sawing, chiseling, or other method. Flame cutting is undesirable but is often necessary. When flame cutting is used, the sample area should be cooled with wet rags, or other means and left with a 2- to 3-inch margin around the area of interest because the heat of the flame can seriously affect the condition of many samples. Small metal samples can be preserved by placing them in labeled bottles or jars and covering them with n-butanol. Larger samples should be rinsed with fresh water, dried, and sealed in marked plastic bags.

D. Other Materials. Other materials should be removed so as to minimize damage and preserved according to guidance given by personnel with expertise in their handling.

E. Transport of Samples. The samples should be packaged in sturdy wooden crates and transported by air freight or rapid surface transport to the analyzing facility.

V. Laboratory Analysis

The techniques used for the analysis of corrosion product, biological, and material samples will, of course, depend on the material to be analyzed and the desired results. Written or photographic documentation of observations and results of testing performed are an important part of the laboratory analysis.

A. Corrosion Products. Corrosion products should be analyzed in accordance with Section 5 of NACE Standard RP-01-73*. Microscopy, X-ray diffraction, X-ray emmission spectography, electron probe microanalysis, infrared spectroscopy, and wet analysis are among the analytical techniques covered in this standard. The main elemental constituent and chemical compounds present in the corrosion products should be identified.

B. Biological Samples. The genus and species of the samples should be identified by a marine biologist. Often, in the deep ocean, new species are discovered or known species are found outside their normally defined habitat.

C. Metallic Samples. Specimens should be subjected to mechanical tests, hardness tests, metallographic examination, and other tests as necessary to evaluate the extent and type of damage to the test samples.

D. Other Materials. Samples of other materials should be analyzed in the laboratory with guidance or assistance from personnel with expertise in their field.

VI. Personnel Requirements for On-Site Inspection

A. Basic Requirements

1. Inspector - a corrosion engineer experienced in evaluating structures after deep-ocean exposure.

B. Desirable Additional Requirements

1. Photographer - person familiar with closeup photographic techniques; preferably a qualified, professional, Navy photographer.
2. Technical Assistant - person familiar with the inspection, sampling, and sample-preservation techniques to be utilized.
3. Mechanical Assistant - person assigned to the inspector for removing material samples, and for other duties.

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* See Reference 1.

VII. Equipment and Supply Requirements

A. Basic Requirements

1. Photographic Equipment and Supplies

a. 35-mm SLR camera with through-the-lens metering and closeup capability.

b. Lenses

(1) Wide angle, approximately 30-mm.

(2) Normal, macro, approximately 50-mm with focal distance of ∞ to approximately 12 inches.

(3) Telephoto, macro, approximately 90-mm, with focal distance of ∞ to approximately 12 inches.

c. Electronic flash (strobe) for camera.

d. Normal or high speed Ektachrome film.

Requirements normally vary from 50 to 250 exposures.

2. Inspection and Miscellaneous Equipment and Supplies

a. Tools for component disassembly. Usually will be available on site from ship's engineer. Check availability.

b. Picks, probes, sampling equipment, etc. Should be brought by inspector.

c. Sample preservation equipment, inspector-supplied. Bottles, jars, plastic bags, etc., and preservative solutions as outlined in Section IV above.

d. Fresh water for rinsing. Usually supplied by ship via a hose, although a pneumatic sprayer can be used.

e. Cutting tools for large samples. Usually available on site from ship's engineer. Check availability.

f. Notebooks and pens or pencils for recording of data.

g. Boxes and packing material for transporting samples. Usually available or can be fabricated on site.

h. pH paper for on-site corrosion product analysis.

B. Desired Additional Requirements

1. Photographic Equipment and Supplies

a. Large format (2-1/4 x 2-1/4, 120, or 4 x 5) camera for black and white photographs.

b. Wide angle, normal (macro) and telephoto (macro) lenses for above. Closeup capability is desired.

c. Flash equipment or flood lamps for camera.

d. Film for camera. Plus-X Panchromatic film preferred. Amount of film required will vary from 50 to 250 exposures.

2. Inspection and Miscellaneous Equipment and Supplies

a. Flame cutting equipment and operators. This will usually be available on site.

VIII. Reporting of Results

The final report should be either an informal report, technical note, or technical report. The informal report can be prepared most rapidly for limited distribution; the technical note or report require more time for preparation but are published in a more polished form and have a wider distribution. The preparation of a short informal report followed by a detailed technical note or report should be considered. A target date for completion of the draft of the preliminary report should be 90 days from the completion of the recovery.

The final report should contain a detailed description of the damage incurred by the structure and a report of the results of the laboratory analysis. Photographs should be included in the report. The conclusions should include an assessment of the damage, its probable cause, the expected lifetime of similar structures, and methods of extending the lifetimes of similar structures. Unexpected corrosion damage should be identified, and recommendations for further studies should be made.

REFERENCES

1. National Association of Corrosion Engineers. Standard RP-01-73: Recommended practice - Collection and identification of corrosion products. Houston, TX, Feb 1973.

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